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Making Money Grow on Trees: Forest Policy in Light of a Carbon Tax

Introduction:

Global warming is an important issue facing humanity. Since the publication of the Stern Report in 2007, it is clear that economics will play a role in any solution. Carbon dioxide emissions from human processes are thought to contribute to rising global temperatures. Roughly 20% of greenhouse gas emissions are due to deforestation (Worldbank). Failure to manage forests to retain and capture carbon is a part of the problem and better management of forests may provide a substantial method to reduce the problem. The total volume of US carbon emissions in 2007 was 6,021.8 million metric tons (EIA). Using population data for the US in 2007 the total volume of greenhouse gas emissions translates into 19.96 metric tons of carbon dioxide emissions per person in the United States. While it is hard to predict the future with any certainty, many estimates show that without a rapid reduction in emissions net of capture, a daunting task given the current emissions levels and large economies coming online world-wide, there could be catastrophic climate change in the next 50-100 years.

This paper focuses on one possible policy, carbon sequestration in forests, specifically the effects of a carbon tax on deforestation. It addresses the question of how a cap and trade system for carbon emissions would affect forests. As trees grow, they naturally sequester carbon, reducing carbon dioxide levels in the atmosphere and providing a positive externality. Logically, the same tax rate per ton of carbon emissions might also provide a subsidy per ton of carbon for sequestration. While this seems readily understandable, it is much harder to create a policy that induces landowners to manage their forests for carbon sequestration. A practical policy to internalize this positive externality might include taxing harvest and subsidizing growth with a certification system. Regardless of the specific policy, carbon sequestration in forests appears to be one part of a strategy to reduce global warming. This paper will try to answer the question: can some government subsidy for carbon sequestration indeed sequester more carbon? It will also try to consider the implications for forest stands and possible considerations for monitoring such a program if a government subsidy could be successful.

Forest policy, creating the incentive to increase carbon sequestration, could directly affect National Forests. Incentives in forestry and agriculture for the private sector to capture carbon are a part of pending legislation S 2191. The issue is even more important internationally. Brazil and other countries offer large, challenging opportunities. In a different approach, the Nature Conservancy has recently launched a fund raising effort to plant a billion trees in the coastal forests of Brazil. A well-designed US forest policy may help other countries improve their policies as well. It is even plausible to believe that the cap and trade system for carbon could become an international market. A secondary goal of this essay is to understand what policies would feasibly allow a private party to receive a “carbon credit” for the amount of carbon captured. This would allow forest subsidies to come from quasi-market forces as part of a global strategy to reduce carbon emissions.

The literature on the subject of global warming, carbon sequestration, and carbon taxes is both substantial and sophisticated. Silviculture, the cultivation of trees in general, is both an industry and a field of study; as a consequence much data exists on costs and processes involved. The literature offers many possible solutions for global warming; carbon taxes are often recommended as a plausible theoretical solution. Carbon sequestration, while it has its limits, can certainly aid in reducing carbon dioxide levels and abating global warming. However, there is still much discussion about what is the best way to address the problem, and many problems with implementation of any proposed policy. In essence, this problem does not have an existing answer, only several competing ideas. This paper aims to contribute to the ongoing discussion of what is a plausible solution.

This issue is a current one on the national policy front. There are three bills that address the issue of offering incentives to increase carbon sequestration which seem in line with a carbon tax philosophy. **S. 1766: Low Carbon Economy Act of 2007 (Leiberman-Warner act)** is a short bill that addresses the issue by setting up a cap and trade market for carbon, one of the specific ways to implement a carbon tax. **S. 2191: America's Climate Security Act of 2007** is a longer and more specific bill which again sets up a cap and trade system for carbon emissions and, more pertinent to this paper, creates a forest and agriculture sequestration program. The Markey bill, **HR 6186**, proposes some support for forests but does not suggest a full subsidy per ton of carbon captured. With these bills, some provisions are in line with the philosophy and planned model set forth in the paper, others are possible alternatives to the system proposed, and still others are in opposition to this model and philosophy. As these bills are currently debated; the issue holds importance and promise to add something new to current information. The paper should offer a critique of these current bills.

Theoretical Framework:

We want to know if forests can be effectively used to sequester carbon as part of a policy to limit greenhouse gases and reduce global warming. Carbon cap and trade legislation, in which a limit on greenhouse gasses would be set and then companies would compete in a free market to buy permits to emit, is frequently proposed to help tackle the problem of global warming. Logically, if there is a set price that must be paid per ton of carbon emitted, there should also be a subsidy on carbon capture. As trees sequester carbon, forests could receive subsidies for the carbon they sequester and be taxed for the carbon released upon cutting. The following model will try to explain how exactly such a subsidy would increase carbon capture through incentives to firms and simultaneously discourage release though reduced cutting. Even if this subsidy would produce the intended effect theoretically, can the concept of a carbon tax be extended in a practical way so that forests hold more carbon?

Before examining the specifics of the model, there is one more major theoretical issue to address: additivity. An important issue is whether to subsidize the stock of carbon or only the flow of newly captured carbon. If firms are only subsidized for new additions of carbon, perverse incentives arise. For example, such a policy would encourage firms to cut trees and replant them for the subsidy, reducing the amount of carbon sequestration. Alternatively, there could be subsidy for each ton of carbon held in forests regardless of when it was sequestered. This could be a very costly framework, making political support difficult.

The ultimate goal is to increase carbon sequestration by encouraging new tree growth through subsidies and discouraging tree harvesting, either by simply removing the subsidy or possibly imposing a tax on the carbon released. We want to encourage firms to plant more trees to increase carbon sequestration and to grow them longer. How much will the subsidy affect the amount of carbon sequestered? How does this subsidy change the decision of when a profit-maximizing firm harvests a tree?

The goal of the model is most easily accomplished in parts. Taking carbon emissions cap and trade legislation as a given, how much should the government pay for the carbon sequestered in a given acre of trees grown and how much should it tax firms for the carbon released by cutting down a given acre of trees? Will an effective policy require both a subsidy and a tax, and if so what is the optimal mix? Here are the three major policies:

1) paying a subsidy for the quantity of carbon captured in a given year (one time payment)
2) paying a rental rate for the total quantity of carbon within a given tree for a given period of time (1 year)
3) tax on the carbon released from cutting

In more general situations, it is possible for it to be appropriate for both a subsidy and a tax to be in place. However, this generally requires differences in monitoring costs for the tax and subsidy that must be captured. There do not seem to be any major differences in monitoring costs, so we expect there to be a corner solution to the optimization of the mixture of the subsidy and tax. It is also important to consider that by tilting policy towards a tax per ton on cutting will require higher incentives for planting. Since the ultimate goal is to increase trees planted, this option seems sub-optimal. Alternatively consider a rental rate strategy, because it seems to encapsulate best paying for all of the carbon sequestered as long as it is sequestered. If the trees are cut, subsidy payments will stop.

Then, after determining the amount of the forest subsidy or tax, the goal is to model the firm's decision making to cut down an acre of trees and see if there are any significant effects in decision making. The model is designed to indicate how much extra sequestration occurs for a given subsidy level. Using the model output, how much subsidy is needed to achieve a given amount of carbon sequestration or the quantity of carbon sequestered within an acre for a given subsidy level can be calculated. At this point the model does not include a planting decision, but further work could most likely do so.

The subsidy is only concerned with the carbon sequestered in a given stand of trees. Because of this, the value of the subsidy continues to increase until there is no longer sequestration (age equals fifty years in the model). The subsidy value is included into the current decision for harvesting a given stand of trees. Using capital theory, a stand of trees will grow until the return on a stand of trees equals a given interest rate and then they will be harvested. While the subsidy is expected to have a positive effect on average stand age, it is plausible to believe that the optimal harvesting age will still be before the stand is saturated with carbon. There is nothing that forces a stand of trees to be grown to full sequestering capacity; the model should give an estimate of how much extra growth can be expected.

Model Framework:

Determining the amount of the forest subsidy for carbon is the first part of the model.

$$Su= ((C*G*P*T)*Sc) \qquad (1)$$

Where: Su is the subsidy per acre of trees

C is the price of carbon per ton as given, here \$10-\$200/ton (a plausible range)

P is the pickling rate, or the proportion of carbon fully sequestered

G is the parabolic estimate of the total basal growth[1] of the tree, from 0-50 years

T is a parameter to give model output in trees per acre (this coefficient makes the empirical estimate for carbon sequestered per acre valid for the model)

Sc is the amount of carbon sequestered per acre of trees,

(NB: longer discussion of these variables follows)

the rental rate for all the carbon in a given acre of trees is given by

$$RR = C*(\sum_{i=1}^{n} G_i)*P*T*Sc \qquad (2)$$

Where $(\sum_{i=1}^{n} G_i)$ accounts for all the carbon that has been sequestered in an acre of trees for their entire life span, paying for all the carbon stored and not simply the new amount sequestered in a given year.

Van Kooten et al (1995) make the point that it is not the age of trees or the volume of the biomass that matters in carbon sequestration, but the rate of timber growth. So, the model will need to be based on the timber growth rate to accurately incorporate carbon sequestration. Tree growth rates start slow, increase rapidly, and then slow down again. Overall, approximate tree growth rates coincide with a parabola because it captures the slope of the important part of tree growth. Different species of trees grow at different rates, which would have a noticeable effect in carbon sequestration. Were the government to adopt the overall plan proposed here for carbon sequestration subsidies, it would be

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[1] While there are many ways to model tree growth, basal growth rate has been used here to try to model the actual sequestration as best as possible.

best to have several different models designed by biologists or researchers at the Forest Service to better reflect the different rates of carbon growth. However, it is also useful to have one general model working, at least initially, with averages that give a general picture of trends nation-wide. In his introduction, Boris Zeide (1993) notes that "probably no biologist believes that one equation would suit all growth processes. This seems to be a belief peculiar to biologists" (1). He goes on to counter with the example that physicists would not have multiple equations for different objects falling in a vacuum. While there are important differences in trees to consider while constructing a model, it is still plausible that a general model will yield some useful results for policy analysis.

The next step is to fit the parabola to model basal tree growth. A concave down parabola is chosen in order to use the y-coordinate of the curve to model the amount of carbon sequestered in a given year. One point that needs to be set empirically is the age of the stand at which carbon is no longer sequestered, which in the model is the point when the y-value of the parabola equals zero. Since the parabola will cross the x-axis twice, the other point is set at $t = 0$ because logically the tree cannot grow, or sequester carbon, when its age is below zero. Running and Gower (1991) state from their empirical estimates of carbon sequestered in trees, "At all sites, stem biomass was still accumulating at Year 50. The Missoula control stand showed a simulated NPP of about 0.8 Mg ha^{-1} $year^{-1}$, but stem primary production was only 0.03 Mg ha^{-1} $year^{-1}$, because of maintenance respiration" (11). This number is sufficiently small that the model takes 50 years as the maximum limit for carbon sequestration; no new sequestration is modeled after tree stand age reaches 50 $\{$when $x=50$, $y=0\}$. The other point when the y-value equals zero (there is no growth) is set for when the x-value is zero. This makes sense because the model anticipates that trees will not start sequestering carbon until they begin to grow (age equals zero), will then begin to sequester immediately as part of the growth process.

The final piece of the parabola that needs to be set is the vertex. Due to empirical estimates, the y-value of the vertex is set at 0.04. Teck and Hilt (1991) estimate potential individual tree basal area growth. The estimates reach a maximum slightly over 0.04 feet^2/year. Basal area is an estimate of area, a specifically measured cross section of a tree, so units are expected to be squared. While Teck and Hilt allow for the fact that disaggregated different species grow at different rates, an aggregated model is more useful for understanding consequences of the subsidy nation-wide. Teck and Hilt's study suggests 0.04 feet^2/year is a reasonable estimate and it is used here. Again, while tree growth is not exactly parabolic, corresponding growth rates are close enough to provide a reasonable estimate.

However, this growth model is for a single tree, and the calculations are given in acres. So, this estimate must be multiplied by some factor to convert it into total growth per acre. Multiplying the single tree growth model by the number of trees per acre accomplished this. This estimate occurs in Baker et al. (1996), and the number of softwood trees per acre before cutting is estimated at 166.

Next is the pickling rate, or the proportion of carbon fully sequestered in the tree. This is included because after a tree is cut, much of the carbon stored, but by no means all of it, is released back into the atmosphere. If there were to be a tax on carbon emitted, it would be important to account for the amount that is not released. For the subsidy part of the model, the time when the trees are alive and actively sequestering carbon, the pickling rate is 100%, or 1. If the model is estimating the amount sequestered after cutting, .35 is used. This is because Heath et al. (1996) reports that on average “approximately 35% of the total C [carbon] removed is stored in products and landfills, 30% has returned to the atmosphere through decay or burning without energy production, and 35% has been burned for energy, partially offsetting fossil fuel use” (4). However, since this model is only concerned with carbon released or sequestered and not offsetting carbon through energy production, the only percentage of carbon that counts as pickled is the amount sequestered in products and landfills: 0.35.

Carbon price, C, is exogenous to the model. Under the given initial conditions, a carbon cap has been legally instituted; the government has set a limit on the amount of carbon emissions for the year and produced permits and sold them in a market, determining the price per ton of carbon. The government could also simply legislate a value per ton of carbon. The exact process in which the price of carbon is set is beyond the scope of this paper, but it is safe to assume that this value will be given. The model allows this parameter to vary over time in order to show what would happen to the subsidy amount if the price rose over time, which is expected as efforts to curb carbon emissions are increased. Stern and others suggest the price of carbon might be near $20 a ton in the near term and rise to $200 a ton or more by the end of the century.

This product is then multiplied by a carbon sequestering per acre coefficient. Nowak et al. estimate this as percent of coverage in an acre (here assumed to be 100%) times a given coefficient. To estimate **annual** amount of carbon sequestered per acre in an area is empirically estimated at 0.00335 (Tons carbon*acre^{-1}*year^{-1}). Because the growth parabola gives tree growth in basal area, which several studies argue promotes a better estimate for carbon sequestration, the basal area must be converted to a measurement of diameter in order for the carbon sequestration coefficient to be applicable.

This model gives an increasing yearly rental rate for carbon per acre from trees aged 1-50. In order to see the total subsidy value for the trees planted on or after the year of legislation, one would simply sum the rental rates over the number of years the trees are growing. But it is also important to know how much tree stands that were planted before legislative implementation are worth. If trees are already at the maximum sequestration age of 50, one simply multiplies the number or years by the maximum rental rate, or RR at i=50. If the trees were some intermediate age, say 30 years, one would start G at i=30 and then sum for the number of years the legislation is in place. In all cases, after the maximum age of 50 has been reached, that is the rental rate on carbon per acre per year unless carbon price were to change.

In order to see how a subsidy would affect the optimal growing point, a model for the value of an acre of trees at a given time is needed. We start by taking the value for timber at 50 years, the age at which the subsidy framework stops increasing the value of the subsidy, to have a comparable timeframe. Wilmott Forest Industries gives the harvest volumes from a forty year stand to be 259m^3 or sawlogs and 24m^3 of pulpwood, the two major types of harvest yields. The study also mentions that stand volume increases at an average of 4.67 to 8.5 cubic meters per acre per year. So, in order to approximate stand volumes at 50 years, ten years of growth at the lower bound average of 4.67 cubic meters a year was assumed. This value was picked for two reasons. First, one can assume that firms cut at whatever the optimal point is at a given interest rate, which would imply returns are low beyond that point in order to not make it economically profitable to cut a year or more later. Second, this slower growth rate matches the rate of the carbon sequestration. By no means would one expect the tree growth rate to be zero like carbon sequestration rate at 50 years, but one would expect it to slow greatly. This implies that over time the value of a carbon subsidy would decrease relative to the market value of the lumber, if only marginally. In order to properly assign how much of the estimated extra volume belongs to sawlogs and to pulpwood, the percentages of the overall volume at forty years was calculated and then the extra growth was split up into the same percentages and added to the existing volume: 91.5% of the volume are sawlogs, 8.5% is pulpwood.

After the total volume of harvest at fifty years is determined, the market value is needed. This is calculated by consulting world timber prices: southern pine sawlogs were worth $59 per cubic meter and Southern pulpwood prices are $27 per cubic meter. These prices are taken from RISI World Timber Price Quarterly, third quarter 2007. So, timber values are: computed as

$$TV = Q_{sawlog}*P_{sawlog} + P_{pulpwood}*Q_{pulpwood}$$

After a total market value has been calculated for a harvest at fifty years, an estimate is needed for the market value of the timber in a given acre of forest at any point in time. This is estimated by using a parabolic function with the maximum value set at the market value for timber at a fifty year stand age. While this may not capture the fluctuations in the market value of an acre of timber fully, it seems reasonable for a model. The estimated volume of a given stand of trees at fifty years of age, derived in the method discussed earlier, is 329.7 cubic feet of total wood volume, 301.7 cubic feet of which is sawlogs and 27.96 cubic feet is pulpwood. Simply multiplying the estimated volumes by the 2007 prices given above yields a value of $24,923.69 in sawlogs and $1056.90 in pulpwood, for a total value of $25,980.59 per acre of fifty-year old trees. Keeping these values in mind gives a standard to judge the relative value of a given subsidy.

To this basic model for the market value for a given stand of trees, estimated non timber market values are added to better incorporate the total worth. Trees offer a myriad of services, many of which are non-monetary benefits. These benefits include: soil stabilization, erosion control, air quality, climate regulation, biological diversity, recreation and tourism, non-timber commercial products, even a range of cultural values. A general equilibrium model would take these prices as endogenous, but for this model estimates must be used to be able to reach a maximization point. Several studies have tried to estimate monetary values for these benefits in order to be more easily accounted for in an economic framework. The Wilderness Society has compiled an executive summary of these estimates of a total non-timber value of US forests to be 63.6 billion dollars, in 1994 US dollars. This is based on the empirically estimated value of $122.20 per acre per annum, again in 1994 US Dollars. So, the Recreational value equals

$$RV = t * 122.20$$

Where t is the number of years the stand has been growing. The costs of a tree are then also incorporated into the model in order to have a more robust estimate of the value of an acre of trees at a given point in time. Cost is defined as:

$$\text{Cost} = \text{fixed planting costs} + \sum_{t=1}^{n} (\text{annual costs})_t \qquad (5)$$

For t = the number of years the trees have been commercially grown.

The study *Costs and Cost Trends for Forestry Practices in the South* (1999) enumerates the costs associated with growing, and those estimates were used to approximate the cost of growing a tree. There are three input costs that only occur once during planting: site preparation for planting, the purchasing of the seedlings to plant, and the physical planting of the seedlings. These costs are estimated at $136.06, $20.90, and $40.40, per acre, in year 2000 dollars. After these one-time startup costs have been accounted for, the remaining seven factors are yearly expenditures. These factors are: chemical treatment (herbicide), prescribed burning as a method of stand management, fertilizer, fire protection, timber cruising (or stand sampling), timber marking (a method of thinning), and pre-commercial thinning. The reported costs per acre per year are:$62.12, $17.70, $43.80, $0.69, $3.45, $25.70, and $82.67, respectively. To calculate the total cost of growing trees of a given age, the model sums the fixed planting costs and then takes the value of the sum of the yearly costs times the number of years the stand has been growing.

Before adding the subsidy to this model for the value of an acre of trees, two other factors must be taken into account. First, all the prices taken as empirical estimates from the literature must be converted into a common, and current, dollar level. This has been done by using the inflation calculator on the Bureau of Labor Statistics website. All prices are put into 2007 dollars. 2007 has been picked over 2008 because of how the estimates are derived: the Bureau of Labor Statistics takes the average of all the months in a given year except for the current year, in which the estimate for the most recent month is used. An annual average is most likely closer to the real level than a fluctuating monthly estimate. The conversion factors for the other prices given in empirical estimates are: $1 in 1994 is equal to $1.40 in 2007; $1 in 2000 is equal to $1.20 in 2007.

The second is picking an appropriate discount rate. There is much debate over what is an appropriate discount rate, especially for environmental issues that are intergenerational. There are very few markets that give interest rates for time periods longer than thirty years. But for long estimates, it is crucial to attempt to get as close an estimate as possible because a very small difference in the interest rate can become a huge discrepancy over a period of, say 200 years. So, two estimates will be used. The first is the conservative estimate of a 4% discount rate. This has been the average rate of returns for government bonds and is used for many estimates currently (Newell and Pizer, 2004). The second case takes the work from Newell and Pizer (2004) into account, which tries to find better estimates for discount rates for long periods of time for environmental issues, where mathematically the discount rate converges to the lowest average of the numbers. Because of this, a discount rate of 2% is alternatively considered, because it is the historical lower limit of the market rate.

This value can be taken as the total value for a given acre of trees before the subsidy is added. Once the already-constructed subsidy term is included, the total equation for estimating the value of a given acre of trees with the values substituted in is:

Value(t)= Timbermodel(t) + Rec*t - Plantcost - Annualcost*t+Subsidy(t)
Where:

Rec is the empirically estimated non-timber value of an acre of trees in a given year

Plantcost is the sum of all one-time growing costs associated per acre of trees

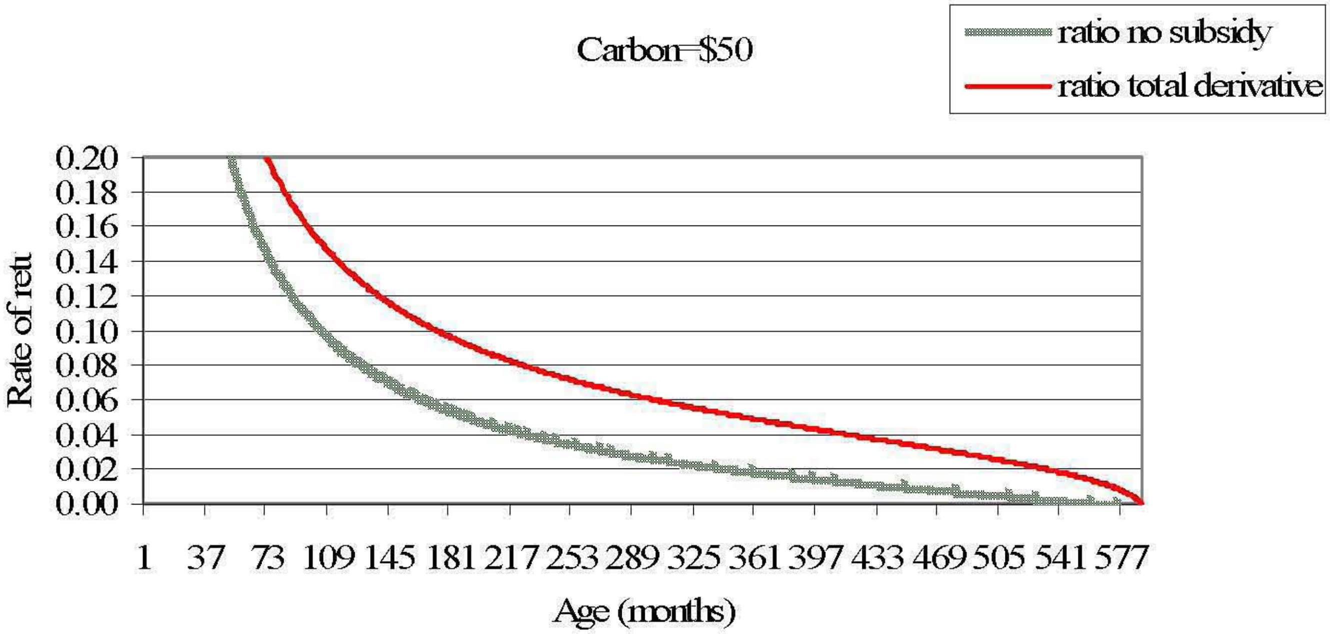
Annual cost is the sum of annual costs of growing a given acre of trees in a year

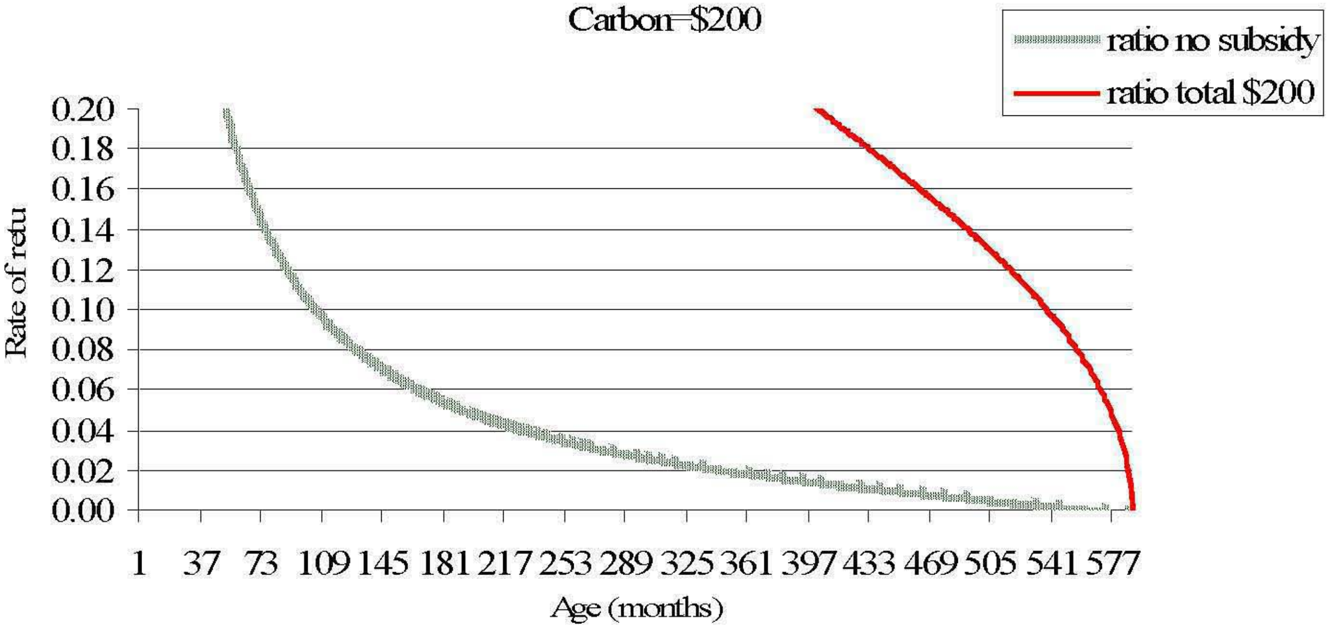
Timbermodel is the model estimating the market value of an acre of timber at t

Subsidy is the integrated model calculating the volume of carbon per acre

The parabola created earlier simulates tree *growth*. Total amount of carbon sequestered in the tree at any given time is the main interest; this can easily be found by integrating the tree growth model and then adding this term to the portion of the model that estimates total value before the subsidy (produced above). In order to find the optimization point, basic capital theory is necessary. Following the above steps create a model estimating the total value of an acre of trees in a given year. Taking the ratio of the derivative to the total value will give the rate of return in a given point in time for the value of the lumber in the tree. This can then be graphed and compared to a picked discount rate to see when the optimal cut point is. Again, the discount rates used will be 2% and 4%. Taking the derivative with respect to t will give the gain in lumber value by year (and the derivative of the tree model is the previously created tree growth portion of the model). This optimization will be compared to the graph of the value of the tree without a subsidy to see how the subsidy affects the cut point.

Below are the graphs for the ratios for the ratio of derivative to total value of the tree, by month, with and without the subsidy included, for a carbon price of both $50 and $200 per ton. These values have been picked because they seem to be about the minimum for an effective price and the projected upper limit for a carbon price for the next century.





The x-axis of each graph is the age of the tree, in months. It is reasonable to assume any producer would be willing to make a more refined decision by month rather than only considering cutting by year, but would probably be unwilling to gauge the optimal age of the tree by day, or even more unrealistically, by hour. Using the capital theory described above, each graph is the ratio of the derivative to the overall value of the tree (the incremental rate of return). The gray line represents the rate of return of the tree without the subsidy for any given month from zero to fifty years of age. The solid line is the ratio of the derivative to the total value of the tree with the subsidy included. The y-axis is the rate of return. The scale is set to display a relevant range of rates of return. To find the optimized tree age, a rate of return is drawn from the market (as previously discussed, the two rates used here are 2% and 4%) and then simply locating the month when that is the rate of return for the tree. The time that elapses between when an acre of trees would be cut with and without the subsidy is represented by the horizontal space between the two graphs.

It is evident that the subsidy makes a greater difference in stand age the higher the price of carbon is. Arguably, even one extra month could make a difference in carbon sequestration when one considers that there is much more growing in a month in spring rather than a month in the dead of winter. Capital theory says that this ratio gives the decision point to cut for a given rate of return, and this information can be used to find two things. The time, in months, between when a firm would cut without a subsidy and when a firm would cut with one can be used to determine how much carbon is sequestered with the subsidy. Because the model estimates the total volume of the given acre of trees at a given point in time and from that calculates the amount of carbon in the acre and how much the carbon is worth, the subsidy amount is readily accessible. The subsidy amount is equal to the value of the carbon in a tree at a price of carbon per ton, taken either from a market or legislation, at the new optimization point. The subsidy is equal to the value that must be added in order to change the optimization point. For example, at a carbon price of $50 per ton, the new optimal age for a tree stand at an interest rate of 2% is 45.33 years. The value of the carbon in an acre of trees that age is $4596.06. So, the subsidy must equal this much in order to create the incentive to shift the optimization point to the new age. This could arguable be paid out in a lump sum of that value, but greater incentives would most likely be created if the subsidy paid for the value of the carbon in the trees is paid yearly, resembling a rental rate. Were an annual rental rate to be designed, discounting would be needed to ensure the total subsidy remained the same. At 4%, the new optimal age is 35.583 years. The value of the carbon in an acre of trees this age is $4158.35, and this will be the value of the subsidy to shift the optimization. At a carbon price of $200 a ton the optimal age with an interest rate of 2% is 49.833 years. The value of the carbon of trees in this scenario is $18,613.68. At a 4% interest rate, the optimal age is 49.333 years and the value of the carbon is $18,608.84. These values can easily be compared to the estimated value of the acre of trees at the age when they are cut. It makes more sense to compare it to the total value of the tree at that age, including both the non-timber values for that age and the costs of growing, rather than the simple estimated market value of the lumber because this is a more accurate estimate of the value. At an interest rate of 2% and carbon price of $50 per ton, the optimal age is 45.33 years. The total value of the tree at this age is $21,825.67. The subsidy in this case is worth 21%. At a 4% interest rate, the total value of the optimal age (35.583 years) is $20,686.07 and the subsidy is worth 20%. For a carbon subsidy of $200 a ton, the total value for the optimal age at a 2% interest rate is $21,685.25, making the subsidy worth 85.8% of the non-subsidized tree value. At a 4% interest rate, the total value of an acre of trees is $21,721.63, making the subsidy worth 85.6% of the non-subsidized tree value.

To calculate how much carbon is in the tree, total growth is needed; this can be calculated by simply subtracting the total tree volume at the month of optimization and subtracting the total tree volume at the optimization month without the subsidy. It is important to do it this way in order to account for the variation in growth rate created by the model. The extra volume in the tree can be used to calculate the amount of carbon sequestered using the same process as before. The value of the extra carbon sequestered is then given by multiplying the value for a ton of carbon by the total amount of carbon sequestered. These numbers for the price of carbon equal to $50 and $200 a ton are reproduced in the table below.

Interest rate	year	total tree volume	carbon sequestered	Carbon=$50	Carbon=$200
0.02	15.5	0.241926188	17.28073924	864.0369618	3456.147847
0.04	15.66667	0.393925679	28.13803245	1406.901623	5627.60649

So the subsidy is effective even at a carbon price of $50 a ton, sequestering between 17.2 and 28.1 extra tons of carbon per acre over a growing period extended by 15 years depending on what interest rate is used. The total worth of this carbon is totally dependent on the value of carbon, but again depending on the interest rate the total amount can be worth anywhere between $864 an $5627 per acre, a sizable incentive.

But the true consequence of a subsidy of this nature becomes clearer in light of some national statistics. In 2007, the EPA reported 736.7 million acres of forest land in the US, a definition that mandates the area be a minimum of 1 acre, have 10% forest cover, and be “not currently developed for non-forest use” (Forestry 2007). Of this land, the Federal Government owns 249.1 million acres; the other 487.6 acres are owned by a combination of companies, individuals, and other non-federal levels of government. More importantly, almost 490 million acres (2/3 of the total forest land area) are designated as “timberland,” or areas that can be harvested for “commercial wood products” (Forestry 2007). The nature of US forest land makes it hard to readily plug into the previously created model, but some interesting ranges still arise in different hypothetical situations. The results from the model are heavily dependent on the age of the tree, or at least the average age of the stand, but this information would be a general estimate at best for such a large area. Consider first the scenario in which the subsidy is in place (at a carbon price of $50 a ton) and extends the optimal harvest age out in all the acres of timberland, where the decision-making ostensibly takes place. Assuming the subsidy altered the optimization point for the entire area, at a discount rate of 2% an additional 8467.5 million metric tons of carbon are sequestered in the stand. This extra carbon sequestered has a value of between 423.3 and 1693.5 billion dollars. At a 4% discount rate 13,787.6 million metric tons of carbon sequestered.

Another interesting scenario is to consider the total volume of carbon sequestered in US forests assuming all the stands were at the constructed optimal sequestration age of 50 years. This is an unrealistic assumption for the entire age of forests in the United States, as is the assumption of 100% tree cover for a given acre (the definition only mandates 10%). Still, with these assumptions in place the total volume of carbon sequestered in forests is 70.16 billion metric tons of carbon. Granted, this value overestimates the amount of carbon actually sequestered in forests, but still gives an idea of the magnitude a subsidy of this nature could truly have for both US forest policy and US carbon policy. The results from the model do show that subsidies on the amount of carbon sequestered can be effective. They do increase stand age and overall amount of carbon sequestered. The amount of carbon sequestered and the dollar value of the carbon are both substantial under this subsidy framework, suggesting it would be effective and expensive to put such legislation in place.

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